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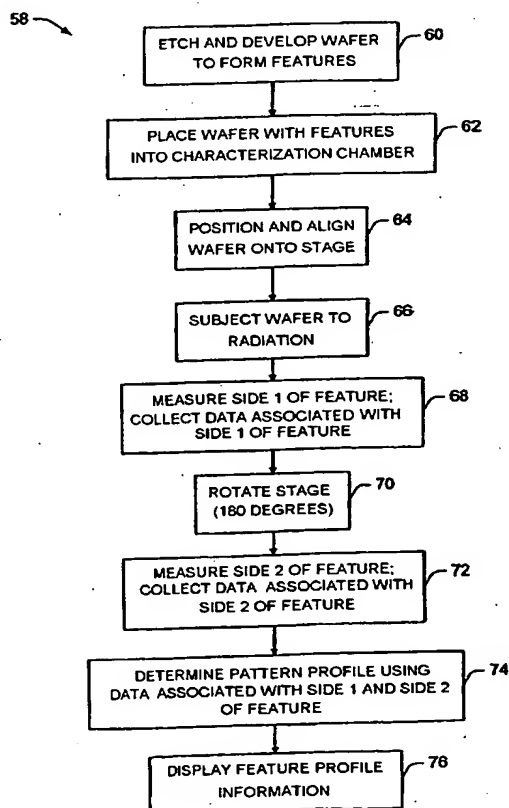
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(54) Title: METHOD TO MEASURE FEATURES WITH ASYMMETRICAL PROFILE



(57) Abstract: The present invention is directed to a method (58) for detecting asymmetry in the profile of a feature (82) formed on a wafer during the process of semiconductor fabrication. The method (58) encompasses directing a beam of light or radiation at a feature (66) and detecting a reflected beam associated therewith (68). Data associated with the reflected beam is correlated with data associated with known feature profile s(19) to ascertain profile characteristics associated with the feature of interest (192). Using the profile characteristics, an asymmetry of the feature is determined (192) which is then used to generate feedback or feedforward process control data (200) to compensate for or correct such asymmetry in subsequent processing.

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METHOD TO MEASURE FEATURES WITH ASYMMETRICAL PROFILE

TECHNICAL FIELD

The present invention generally relates to the fabrication of a semiconductor device and more particularly to a method and a system for characterizing a symmetry of feature profiles and using that information to optimize symmetric profile patterning.

BACKGROUND ART

In the semiconductor industry, there is a continuing trend toward higher device densities. To achieve these high densities there has been and continues to be efforts toward scaling down device dimensions (e.g., at submicron levels) on semiconductor wafers. In order to accomplish such high device packing density, smaller and smaller features sizes are required. This may include the width and spacing of interconnecting lines, spacing and diameter of contact holes, and the surface geometry such as corners and edges of various features.

The requirement of small features with close spacing between adjacent features requires high resolution photolithographic processes. In general, lithography involves the transfer of a pattern or image from one medium to another, as from a mask to a wafer. In particular, a mask can be used to protect one area of the wafer while working on another. For example, a photoresist is applied to a wafer and aligned to a mask. Then light such as ultraviolet radiation can be projected through the mask, thereby exposing the photoresist with the mask pattern. The wafer is then developed to remove the exposed photoresist and baked to harden the remaining photoresist pattern. Areas not covered by the hardened photoresist are then etched away, and the wafer is inspected to ensure the image transfer from the mask to the top layer is correct. This process is repeated several times until all active devices and features have been formed.

During the fabrication process of a semiconductor, for example, during etching, thin film deposition or chemical mechanical polishing, features may become non-uniform in their profile structures. For example, the etching away of a polysilicon feature such as a gate may result in the feature having an asymmetric profile such that one side of the feature is situated at about a 90° angle to the substrate but the opposite side of the feature is situated at an angle greater than or less than the first side. This asymmetry in the feature profile may lead to performance problems or degradation, especially in extremely small devices, caused by the shallow or malformed features in the front end. Inevitably, the device may exhibit poor resistance or conductivity or fail other types of parametric and/or functional criteria, and may thus be rendered sub-standard due to the asymmetric feature profiles.

Therefore, in a production line of semiconductor devices, there is a need to examine the profile of structures such as a feature formed on a wafer quickly, without contacting or destroying the structure prior to the completion of the semiconductor device. There is also a need to optimize fabrication process parameters during semiconductor production to provide more exact control and detection of asymmetric feature profiles.

DISCLOSURE OF INVENTION

The following presents a simplified summary of the invention in order to provide a basic understanding of some aspects of the invention. This summary is not an extensive overview of the invention. It is intended to

neither identify key or critical elements of the invention nor delineate the scope of the invention. Its sole purpose is to present some concepts of the invention in a simplified form as a prelude to the more detailed description that is presented later.

The structural profile of features formed on a wafer may affect the conductivity and overall performance of a semiconductor device. Asymmetrically formed features may result in reduced performance of the semiconductor device. Thus there is a need to obtain information on feature profiles to determine the quality and preciseness of a fabrication process to prevent asymmetric feature profiles.

The present invention is directed to a method and a system for non-destructively, efficiently and accurately detecting asymmetry in the profile of a feature formed on a wafer during the process of semiconductor fabrication. The system comprises a light source, a stage for a patterned wafer sample, a detector, a processor system including a memory and a processor associated therewith, and a display unit. According to another aspect of the present invention, the system is placed *in-situ* a semiconductor fabrication line for immediate detection and control to optimize subsequent feature formation.

The method encompasses directing a beam of light or radiation at a first side of a feature. A detector captures and measures a reflected beam associated with the first side of the feature. The light source or the feature is rotated (*e.g.*, about 180 degrees) with respect to the other from an original position and a beam of light is now directed to a second side of the feature. A detector again captures and measures a reflected beam associated with the second side of the feature and the two sets of measurements (from the first and the second sides) are correlated by a processor system using a predetermined correlation threshold. Once correlated, the symmetry or asymmetry of a feature profile is determined.

In particular, the present invention describes a method of detecting asymmetry of a feature profile and comprises placing a patterned wafer with at least one feature formed (*e.g.*, a grating) thereon into a characterization chamber. An incident beam of radiation is then directed at a first side of a feature and a first reflected beam associated with the first side of the feature is detected. An incident beam of radiation is then directed at a second side of the feature and a second reflected beam associated with the second side of the feature is detected. Using the data collected from the first side and the second side of the feature, a pattern profile is determined. By analyzing the determined pattern profile, a type and degree of feature asymmetry is ascertained and utilized to generate feedback or feedforward control data to account and adjust for such asymmetry.

Another aspect of the method comprises directing an incident beam of polarized light at a first side of a feature and detecting a reflected beam to determine a change in the state of polarization before and after reflection. The change in polarization is then employed to ascertain properties associated with the reflecting boundary (*e.g.*, the feature profile). A light source or a stage is then rotated, for example, about 180 degrees from its original position, causing the beam of light to be directed at a second side of the feature and the measurement is performed again.

Another aspect of the present invention allows for direction of a broadband wavelength range of incident light on the feature of interest in a direction generally normal to the wafer surface. The reflected light intensity as a function of wavelength is then detected. The reflection data is then compared to a database of reflection profiles containing numerous reflection signatures associated with different known feature profiles.

As a result of the comparison, the profile of the feature of interest and its associated asymmetry is identified. Such identification is then used to generate feedback or feedforward process control data to compensate or correct for such asymmetry in subsequent processing.

In accordance with yet another aspect of the present invention, scatterometry is employed to ascertain the asymmetry of a test structure such as a grating. An incoming light spectra reflects off of the test structure and a detector collects a reflected light intensity and phase profile as a function of wavelength. The profile data is then compared with a database of intensity and phase signatures associated with known feature profiles to identify the profile of the test structure. This process is then repeated for an opposite side of the test structure to ascertain an asymmetry associated therewith. The asymmetry determination is then employed to generate feedback or feedforward control data to compensate for the asymmetry or modify the process to prevent subsequent feature asymmetry.

The invention extends to features hereinafter fully described and features particularly pointed out in the claims. The following detailed description and the annexed drawings set forth in detail certain illustrative examples of the invention. These examples are indicative of but a few of the various ways in which the principles of the invention may be employed. Other ways in which the principles of the invention may be employed and other objects, advantages and novel features of the invention will be apparent from the detailed description of the invention when consider in conjunction with the drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a partial block diagram illustrating an exemplary detection system according to the present invention.

FIG. 2 is a flow chart illustrating a method for characterizing a feature profile formed on a wafer, measuring a first and second side of the feature, and then determining its pattern profile.

FIGS. 2a through 2e are schematic illustrations of exemplary pattern profiles associated with a feature formed on a wafer.

FIG. 3 is a flow chart illustrating a method for characterizing a profile of a feature formed on a wafer using ellipsometry.

FIGS. 3a and 3b are schematic illustrations demonstrating aspects of a method of the invention as described in FIG 3.

FIG. 4a and 4b are exemplary graphs of intensity and phase, respectively, as a function of wavelength associated with a side of a feature measured by an ellipsometer.

FIG. 5 is a partial block diagram illustrating an exemplary detection system according to the present invention.

FIG. 5a is a graph of power spectral density (PSD) as a function of spatial frequency for a scatterometer.

FIG. 6 is a partial block diagram illustrating a detection system employing a database according to the present invention.

FIG. 6a is a flow chart illustrating a method for characterizing a feature profile using a database.

FIG. 6b is a flow chart illustrating a method for characterizing a feature profile for immediate feedback into fabrication process parameters to optimize subsequent feature formation.

MODES FOR CARRYING OUT THE INVENTION

The present invention will now be described with reference to the drawings wherein like reference numerals are used to refer to like elements throughout. In accordance with one aspect of the present invention, a method will be described with reference to the detection of an asymmetric profile of a feature formed on a wafer employing ellipsometry, reflectometry or scatterometry. Upon ascertaining the degree of asymmetry associated therewith, the method further comprises generating feedback or feedforward process control data to compensate or adjust subsequent processing to mitigate such asymmetry. It should be understood that the description of these aspects are merely illustrative and that they should not be taken in a limiting sense.

Referring now to the figures, several aspects of the present invention are presented. FIG. 1 is a schematic illustration of an exemplary system using an optical technique such as ellipsometry, reflectometry or scatterometry to determine a pattern profile or to characterize a symmetry of a feature profile. It is to be appreciated that the system shown in FIG. 1 is not necessarily drawn to scale to illustrate the teachings of this invention.

Ellipsometry is one tool which can be employed to characterize the symmetry or lack thereof of a feature profile. Ellipsometry is an optical technique devoted to the analysis of surfaces. It is based on the measurement of the variation of the polarization state of the light after reflection on a plane surface. The strong advantages of ellipsometry are its non-destructive character, its high selectivity due to the measurement of the phase of the reflected light, its large measurement range and the possibilities to control real time complex processes.

Spectroscopic ellipsometry employs linearly polarized incident light and exploits the fact that the component waves of incident light experience different amplitude attenuations and varying phase shifts upon reflection from a surface. Therefore the state of polarization changes upon reflection upon the surface. In accordance with one exemplary aspect of the present invention, an ellipsometer measures a phase of a reflected light beam as a function of wavelength and an intensity of a reflected light beam as a function of wavelength, the analysis of which corresponds to a particular structure. A detector collects the phase and intensity data and then communicates that information to a processor system where the data is calculated and saved into memory for future use. The information is then displayed by a monitor, a printer or any other displaying device. The information can also be fed back into fabrication process parameters to optimize subsequent feature formation.

In particular, using ellipsometry, an incident light, for example, light having multiple wavelength components such as about 100 nm to about 1000 nm, with an incident angle and a polarization angle, reflects off of a feature or test structure (e.g., a grating). The reflected light exhibits a change in its electric field components, its phase and its polarization due to the difference between the refractive index and reflectance between the test structure and the wafer substrate. As a result, a complex coefficient ratio may be obtained.

The profile of the test feature which is collected *via* the detector and is later compared against a database of data corresponding to known feature profiles to ascertain the profile of the test structure of interest. By repeating such analysis from the other side, feature profile data associated with both sides of the feature is

determined and an asymmetry associated therewith is identified. Using such asymmetry information, a processor is used to determine process anomalies that may be associated with contributing to such asymmetry. Feedback or feedforward process control data is then generated to compensate or correct subsequent processing to mitigate for the detected asymmetry.

According to another exemplary aspect of the present invention, spectroscopic reflectometry employs a normal-directed incident beam of light containing multiple frequency components, for example, about 100 nm to about 1000 nm, to collect a reflected light intensity distribution over the wavelength range. That is, a light is directed to a test structure (e.g., a grating) in a generally normal or perpendicular fashion, and an intensity profile, which is a function of wavelength, is collected from the reflected light. Since the incident light is generally perpendicular to the surface, data regarding the profiles of both sides of the feature may be ascertained (e.g., assuming both sides of the feature(s) of interest exhibit non-perpendicular profiles which are not re-entrant). Accordingly, data associated with the asymmetry of the feature profile may be collected in a single measurement. The intensity distribution data is then compared to a database of intensity distributions associated with known feature profiles to identify the profile of the structure of interest. Such information is then utilized to ascertain the asymmetry of the feature of interest and, using such asymmetry information, a processor is used to determine process anomalies that may be associated with contributing to such asymmetry. Feedback or feedforward process control data is then generated to compensate or correct subsequent processing to mitigate for the detected asymmetry.

Scatterometry is another tool which can be employed to characterize a feature profile. Scatterometry is a technique that involves directing a light beam, typically a laser, on an area to be characterized and measuring the angular distribution of the light that is elastically scattered from that area. An exemplary system may employ one or more light sources arranged to project light on respective portions of a feature and one or more light detecting devices to collect light reflected by the feature. A processor system is operatively coupled to one or more detecting devices. The detector device measures and the processor system calculates a power spectral density (PSD) as a function of spatial frequency. PSD is a measure of scattered power per unit of spatial frequency.

FIGS. 1-6 of the present invention illustrate a method and a system using ellipsometry, reflectometry or scatterometry for gaining information on the structural profile of features formed on a wafer or substrate to optimize processing and performance of semiconductor devices and to reduce the variability in feature profile asymmetry.

In FIG. 1, a characterization system 10 comprises a light source 20, a stage 22, a detector 24, a processor system 26 having a memory 30 associated therewith, and a display unit 40, wherein the processor 26 is associated therewith and/or coupled to the detector 24. The light source 20 is positioned to direct an incident beam of radiation 52 at a sample 54. The sample 54 comprises a wafer 61 having a feature 61a formed therein or thereon. It should be appreciated that the wafer 61 may contain more than one feature, as may be desired.

The stage 22 comprises a rotating base or other mechanism which will cause the stage to rotate. In another aspect of the present invention, the stage 22 comprises a mechanism for rotating the sample 54 while maintaining the position of the stage 22. Alternatively, the stage 22 may be fixed and the light source 20 may be

rotated about the sample 54. The detector 24 detects a reflected beam 56 and communicates this data to the processor system 26. The processor system 26 collects this data and determines a pattern profile of a feature using the collected data. The determined pattern profile can then be sent to the display unit 40, stored in the memory 30 of the processor system, or fed immediately back into the production line to alter the fabrication process of subsequent features.

As illustrated in Fig. 1, the light source provides incident light at an angle with respect to the wafer 61. Although Fig. 1 illustrates an angle of incidence between 0° and 90° , it should be understood that the angle may be normal or generally perpendicular to the wafer 61, for example, in instances where a reflectometry analysis is conducted.

FIG. 2 is a flow chart illustrating a method 58 for determining a pattern profile of a feature formed on a wafer using, for example, the system shown in FIG. 1. The method 58 begins at step 60 in which a wafer 61 is processed, for example, etching a film (e.g., polysilicon), or developing an exposed photoresist, to form a patterned feature 61a thereon (FIG. 1). For example, a gate structure may be formed on a wafer or a grating. Other features which can be formed on a wafer include a trench or a via, for example. In step 62, the patterned wafer 61 is placed into a characterization chamber. At step 64, the etched wafer 61 is positioned and aligned onto the stage 22 (FIG. 1). The etched wafer 61 is subjected to radiation 52 in step 66 (FIG. 1). For example, for an ellipsometry analysis, the radiation may be an incident beam of polarized light at a range of wavelengths, such as a range of about 100 nm to about 1000 nm. The incident beam of radiation 52 is directed generally at a side of the feature 61a. Alternatively, for a reflectometry analysis the incident beam (e.g., unpolarized light) is incident upon the feature 61a in a generally perpendicular fashion.

At step 68, a reflected beam associated with a first side of the feature 61a is detected and measured using, for example, the detector 24. In step 70, the stage 22 is rotated from an original position (see, e.g., FIGS. 3a and 3b). For example, the stage can be rotated about 180 degrees from an original position such that a second side exposed to radiation is a side opposite the first. Alternatively, the source of radiation 52 can be rotated about the feature 61a so as to be directed generally at a second side of the feature. In step 72, a reflected beam associated with the second side of the feature 61a is detected and measured.

In one aspect of the invention, the incident beam of radiation 52 is directed to substantially the entire side of the feature. In another aspect of the invention, the incident beam of radiation 52 is directed to portions of a side associated with the feature, wherein the irradiated portions of the first side substantially correspond to the irradiated portions of the second side. The desired portions of a side associated with a feature to be irradiated may differ depending on the type of feature.

In accordance with one exemplary aspect of the invention, with a reflectometry analysis, the incident radiation is directed toward the wafer in a generally perpendicular fashion and consequently the steps of directing radiation to different sides is not necessary, nor is a rotation of the feature necessary since light will reflect off both sides of the feature 61a when normally incident thereon (for non-perpendicular, non-re-entrant profiles), and thus data associated with both sides of the feature 61a may be collected in a single step.

The data associated with the first and second sides of the feature 61a are collected, for example, by the processor system 26 (FIG. 1). At step 74, the method 58 determines a pattern profile using the collected data

associated with the first and second sides of the feature 61a. For example, the pattern profile of a gate structure formed on the wafer could be determined as shown in FIGS. 2a, 2b, 2c, 2d, or 2e. The method ends at step 76 in which a determined profile structure of the feature 61a is displayed to an operator, for example. This information can also be kept or maintained in a database for further analysis or displayed using any other type of output device such as a monitor or a printer.

In accordance with one exemplary aspect of the present invention, the characterization process described in FIG. 2 is performed using an ellipsometer in a method 78. Referring to FIG. 3 together with FIGS. 3a and 3b, the method 78 begins at step 80 in which an incident beam of polarized light having a predetermined range of wavelengths is directed at a stage 81 whereupon a wafer with a feature 82 has been aligned. The exemplary range of wavelengths of the incident light is about 100 nm to about 1000 nm. At step 84, a beam of polarized light 86 is directed generally at a first side 87 of the feature 82 (FIG. 3a). It should be appreciated that the term "generally" indicates that the beam of light 86 may be directed to any area associated with the first side 87 of the feature or a second side 94, as the case may be. It should also be appreciated that a filter (not shown) may be used to eliminate any background "noise" associated with this method.

In step 88, a detector detects and measures an intensity and a phase of a first reflected beam 90 as a function of wavelength. An example of this type of data is illustrated in FIGS. 4a and 4b, respectively. As a further note, detection may be accomplished using any detector known in the art and suitable for achieving the objectives of this invention. In step 92, the stage 81 is rotated about 180 degrees from its original position. An incident beam of polarized light 93 having a predetermined range of wavelengths is directed toward a second side 94 of the feature 82 (step 96). Again, the exemplary range of wavelengths is about 100 nm to about 1000 nm.

At step 98, a detector detects and measures an intensity and a phase of a second reflected beam 100 as a function of wavelength. This data is communicated to and collected by a processor system 26 (FIG. 1). In step 102, a processor system 26 (FIG. 1) determines whether the data collected from the first side 87 and the second side 94 of the feature 82 correlate. For example, the intensity data and the phase data can each be correlated for the first and second sides, respectively. In one aspect of this invention, "correlate" is defined as a statistical correlation analysis between the data of the first and second sides. Symmetry or asymmetry is determined according to a correlation threshold (e.g., symmetry if correlation is greater than 0.9 or some other predetermined threshold).

According to another aspect of this invention, "correlate" is defined as comparing the determined pattern profiles of the first side and the second side, respectively, for example, by a comparison of the pattern profiles from the first and second sides to determine whether the profile of the feature is asymmetric *via* the processor (e.g., within X% of one another or Y% of one another, wherein X or Y is predetermined according to characterization criteria). If the question is answered in the affirmative (YES), then the feature is judged acceptable (step 104); and the method 78 ends. However, if the amount of correlation is insufficient, then the method proceeds to step 106. Once a feature profile is determined to be asymmetric, various steps can follow. For example, the information may be provided to an operator for further testing of the subject wafer, the wafer may be discarded from the production line either manually or automatically, or the data collected from the wafer

may be used to optimize one or more process parameters of the semiconductor fabrication process, as will be described in greater detail *infra*.

With reference to the method 78 as described in FIG. 3, a method 109 represents another aspect of the present invention which encompasses using a scatterometer to characterize a feature profile as symmetric or asymmetric. An example of a scatterometer system 107 suitable for the characterization process is shown in FIG. 5. The method 78 and the method 109 differ in a few key respects. For example, the method 109 provides for directing an incident beam of nearly collimated light 91 (FIG. 3, Step 80, 84) toward a first side of a feature 82. In the following step, a detector 95 detects a first reflected beam and a processor calculates a power spectral density (PSD) as a function of spatial frequency. PSD is a measure of scattered power per unit of spatial frequency. An example of such data associated with a side of a feature is illustrated in FIG. 5a. Method 109 continues accordingly as described above in FIG. 3 to determine whether the feature profile is symmetric or asymmetric using the scatterometric data.

Alternatively, one or more incident beams of light may be directed at a side associated with a feature either in succession or simultaneously. In another aspect of the present invention, one or more detectors may be used to collect relevant data. In yet another aspect of the present invention, the light source 91 may be stationary with respect to the stage 22. In still another aspect of the present invention, the light source 91 may be non-stationary with respect to the stage 22 such that the detector 95 detects reflected light at timed intervals as the light source 91 rotates around the feature 82.

In accordance with one exemplary aspect of the present invention, the above discussed systems and methods allow a use to identify whether a patterned feature exhibits an asymmetric feature profile. In addition to simply ascertaining whether asymmetry exists, the systems and methods may also be operable to ascertain an amount of asymmetry between the opposing sides of a feature via, for example, use of a database containing known profile data signatures (*e.g.*, via correlation).

Referring now to FIG. 6, an exemplary illustration of a characterization chamber system 108 for determining a pattern profile of a feature using a database is shown. FIG. 6 also illustrates placing the system 108 *in-situ* for immediate detection and control of asymmetric feature profiles during semiconductor fabrication 130, which will be discussed later. According to FIG. 6, a database 120 is connected to and communicates with the processor system 26. The database comprises sets of data corresponding to known feature profiles. The types of data depend on the type of device used to conduct the characterization of a feature. For example, if one uses an ellipsometer to characterize a feature profile (FIG. 3), then the database comprises sets of phase and intensity as a function of wavelength associated with known feature profiles, wherein one set of phase and intensity as a function of wavelength corresponds to a side of a feature having a known side profile of that side.

Likewise, if a reflectometry system/method is being employed, data sets comprising reflectance intensity as a function of wavelength may be measured and compared against a database of intensity distributions associated with known feature profiles. Lastly, for example, if a scatterometry system/method is utilized, intensity/phase distributions or power spectral density functions may be measured and/or calculated and compared against a database of such data signatures associated with known feature profiles.

As discussed above, the asymmetry of the profile is determined by determining the profile characteristics of each side of a feature by comparing collected data associated with the feature of interest to a database of data signatures associated with known feature profiles and then ascertaining the asymmetry using such information for both sides of a feature. According to another exemplary aspect of the present invention, the database of signatures associated with known feature profiles may be utilized to train a neural network. Subsequently, a data set associated with a feature under analysis may then be put into the trained neural network which will then provide a determination of the state of the feature profile. Using the determination associated with both sides of the feature, the processor is operable to determine an asymmetry associated with the feature of interest.

Turning to FIG. 6a, a flowchart which illustrates a method 110 for characterizing a symmetry of a feature profile using the database 120 (FIG. 6) is shown. The method 110 begins with steps similar to method 78; for example, steps 80 through 98 (FIG. 3). After performing a step similar to step 98 (FIG. 3), method 110 continues to step 140 in which the database 120 is compared to the phase and intensity data (e.g., for an ellipsometry or scatterometry system/method) associated with a first side and a second side of a feature, respectively. Following step 140, the profile information is displayed or communicated (step 144). It is to be appreciated that the process described in FIG. 6a is merely exemplary of performing the characterization process using a database. For example, the comparison between the collected data and the database could occur after the first side is measured and again after the second side of the feature is measured. In addition, the comparison may comprise a statistical correlation in which a match is found for any correlation that exceeds a predetermined threshold. Further, if multiple data sets match the correlation, the data set which exhibits the highest correlation may be selected.

Alternatively, if reflectometry is being employed, simply an intensity distribution data set may be utilized. If scatterometry is being employed, not only may the intensity and phase distribution data be used, but a power spectral density may be calculated and utilized, as may be desired.

According to another aspect of the present invention, FIG. 6b illustrates an exemplary method 180 in which information associated with a feature profile, which is determined to be asymmetric, is immediately fed back or fed forward into fabrication process parameters 130 to optimize semiconductor formation. For example, the method 58 as described in FIG. 2 is placed *in-situ* a semiconductor fabrication line.

Various types of process conditions may contribute to feature asymmetry. For example, in a chemical-mechanical polish (CMP) process, asymmetry may result from slurry composition, polish pad(s) condition or wear, polish pad movement control, etc. In such circumstances, an identification of profile asymmetry may be utilized by the processor to generate feedback control data to alter one or more of the above process parameters to reduce such asymmetry in subsequently formed features.

In accordance with another exemplary aspect of the present invention, profile asymmetry may be caused by lens aberrations such as coma. In such circumstances, the asymmetry determination by the processor may be utilized by the processor to vary an exposure condition globally or adjust a pupil filter to alter an intensity or phase of light globally or locally in one or more portions of the image field to thereby compensate for the aberration for subsequently formed features.

In accordance with yet another exemplary aspect of the present invention, asymmetric features such as polysilicon gates can affect subsequent ion implantation steps, thereby negatively causing non-uniformity in spatial doping concentration in the source/drain regions. In such circumstances, the present invention contemplates utilizing the asymmetry information determined by the processor to generate feedforward process control data to vary a subsequent ion implantation step to compensate for the profile asymmetry and thereby establish substantially spatially uniform source/drain regions.

For example, if one side of a polysilicon gate structure is determined to have a substantially more sloped sidewall than the other side of the gate, a tilt implant may be associated with the implantation of that side of the gate so as to ensure more dopant under a portion of the shaped profile than would otherwise exist in that region with a conventional implantation step. This and other type of feedforward compensation adjustments may be employed by the processor via process control data in view of the asymmetry determination. For example, an amount or type of process control data may be a function of an amount of asymmetry determined, as may be desired.

The method 180 begins with many similar steps as previously described in FIG. 2; for example, steps 60 through 72. Following performance of the similar step 72, the method 180 continues with step 190 in which collected data associated with a first side and a second side of a feature are correlated as specified in the method 58. Alternatively, a database such as is used in method 110 could be employed to determine a profile of the feature (step 190).

In step 192, a processor system must determine if the first side and the second side of the feature are symmetric. If the response is in the affirmative (YES), then the profile is determined symmetric (step 194) and the method 180 stops (step 196). However, if the response is negative, then the profile is determined asymmetric (step 198) and the collected data associated with this feature is fed back into fabrication process parameters 130 so that adjustments are made to optimize subsequent feature formation (profiles) (step 200).

For example, as described above, changing fabrication process parameters includes altering an etching process such as altering a plasma chemistry, pressure, etc. in a plasma etching process to increase or decrease a slope of a sidewall of the feature, thereby improving a symmetry of subsequent features. Alternatively, changing fabrication process parameters may include altering one or more factors associated with chemical mechanical polishing (CMP) pads, the CMP slurry, etc. to increase or decrease an amount of polishing on either the first or the second side or both sides of the feature, or altering an alignment of the wafer to compensate for a coma effect associated with a stepper lens during an etching process. It should be appreciated that other process parameters that influence feature formation may also be altered and such alterations are contemplated as falling within the scope of the present invention. In addition, more than one process parameter could be altered depending on the information associated with the asymmetric feature profile.

It is also to be appreciated that the methods 78 and 109 (FIG. 3) could also be placed *in-situ* a semiconductor fabrication line to perform the method 180.

In another aspect of the present invention, a trained neural network is incorporated into a processor system to characterize the symmetry associated with a feature profile. For example, a trained neural network

could be introduced into the methods described above in FIGS. 3, 6a or 6b to determine the symmetry of a feature profile.

Although the invention has been shown and described with respect to certain aspects, equivalent alterations and modifications will occur to others skilled in the art upon the reading and understanding of this specification and the annexed drawings. In particular regard to the various functions performed by the above described components (systems, devices, assemblies, etc.), the terms used to describe such components are intended to correspond, unless otherwise indicated, to any component which performs the specified function of the described component (*i.e.*, that is functionally equivalent), even though not structurally equivalent to the disclosed structure that performs the function in the herein illustrated exemplary aspects of the invention. In addition, while a particular feature of the invention may have been disclosed with respect to only one of several aspects, such feature may be combined with one or more other features of the other aspects as may be desired and advantageous for any given or particular application. Furthermore, to the extent that the term "includes" is used in either the detailed description and the claims, such term is intended to be inclusive in a manner similar to the term "comprising."

INDUSTRIAL APPLICABILITY

The apparatus and associated method may be used in the field of lithography development and semiconductor processing to provide improved linewidth control when fabricating integrated circuits or the like.

CLAIMS

What is claimed is:

1. A method (58) of detecting asymmetry of a feature profile (87, 94) comprising:
directing (66) an incident beam (86) of radiation generally at a first side (87) of a feature (82);
detecting (68) a first reflected beam (90) associated with the first side (87) of the feature (82);
directing (66) an incident beam (93) of radiation generally at a second side (94) of the feature (82);
detecting (72) a second reflected beam (100) associated with the second side (94) of the feature (82); and
determining an asymmetry (74) of the feature (82) using the detected first reflected beam (90) and the detected second reflected beam (100).
2. The method (58) of claim 1, wherein detecting (68) the first reflected beam (90) or the second reflected beam (100) comprises detecting a reflected beam intensity as a function of wavelength (88, 98).
3. The method (58) of claim 2, wherein detecting (68) the first reflected beam (90) or the second reflected beam (100) further comprises detecting a reflected beam phase as a function of wavelength (88, 98).
4. The method (58) of claim 2, wherein determining an asymmetry (74) of the feature comprises:
comparing (140) the reflected beam intensity of the first side and the second side to a database containing a plurality of intensity profiles associated with known feature characteristics; and
determining a side profile (190, 192, 194, 198) associated with the first side and the second side of the feature, respectively, based on the comparison.
5. The method (58) of claim 4, wherein determining (190) a side profile associated with the first and second sides of the feature comprises correlating data associated with the first side (87) and the second side (94) of the feature (82) to the plurality of profiles associated with known feature profiles, respectively, using a predetermined correlation threshold.
6. A method (180) of determining asymmetry associated with a feature (82) and generating process control data associated therewith, comprising the steps of:
directing (66) radiation at the feature (82);
detecting (68, 72) reflected radiation from the feature (82);
ascertaining (192) an asymmetry of the feature (82) using the detected reflected radiation; and
generating process control data (200) based on the asymmetry of the feature (82).
7. The method (180) of claim 6, wherein directing radiation comprises directing linearly polarized light at a non-perpendicular angle to a substrate having the feature (82) thereon, wherein the linearly

polarized light has a range of wavelengths of about 100 nm to about 1000 nm, and wherein detecting reflected radiation comprises:

- detecting a reflected radiation intensity distribution over the range of wavelengths; and
- detecting a reflected radiation phase distribution over the plurality of wavelengths.

8. The method (180) of claim 7, wherein ascertaining (192) the asymmetry of the feature (82) comprises:

correlating (190) the detected reflected radiation intensity distribution and the detected reflected radiation phase distribution to a database containing a plurality of intensity distributions and phase distributions associated with known feature profile characteristics; and

identifying (190) a known feature profile characteristic which most has an intensity distribution and a phase distribution which most closely correlates to the detected reflected radiation intensity distribution and the detected reflected phase distribution of the feature.

9. The method (180) of claim 6, wherein the process control data (200) comprises feedback process control data used to alter a semiconductor process step to reduce feature asymmetry in subsequent fabrication of like features.

10. The method (180) of claim 6, wherein the process control data (200) comprises feedforward process control data to alter a subsequent processing step related to the feature to thereby reduce an effect of the feature asymmetry.

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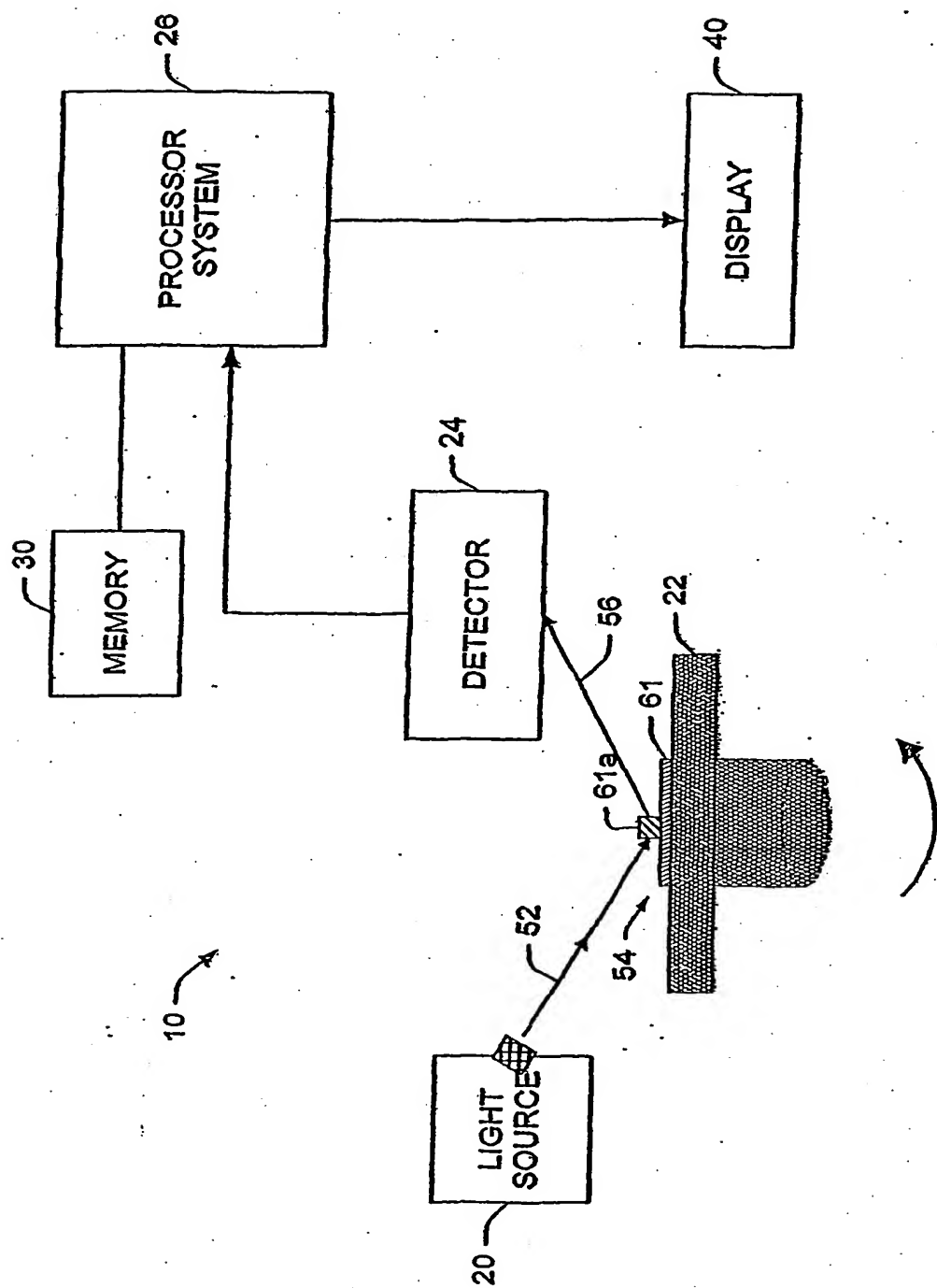


FIG. 1

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58 →

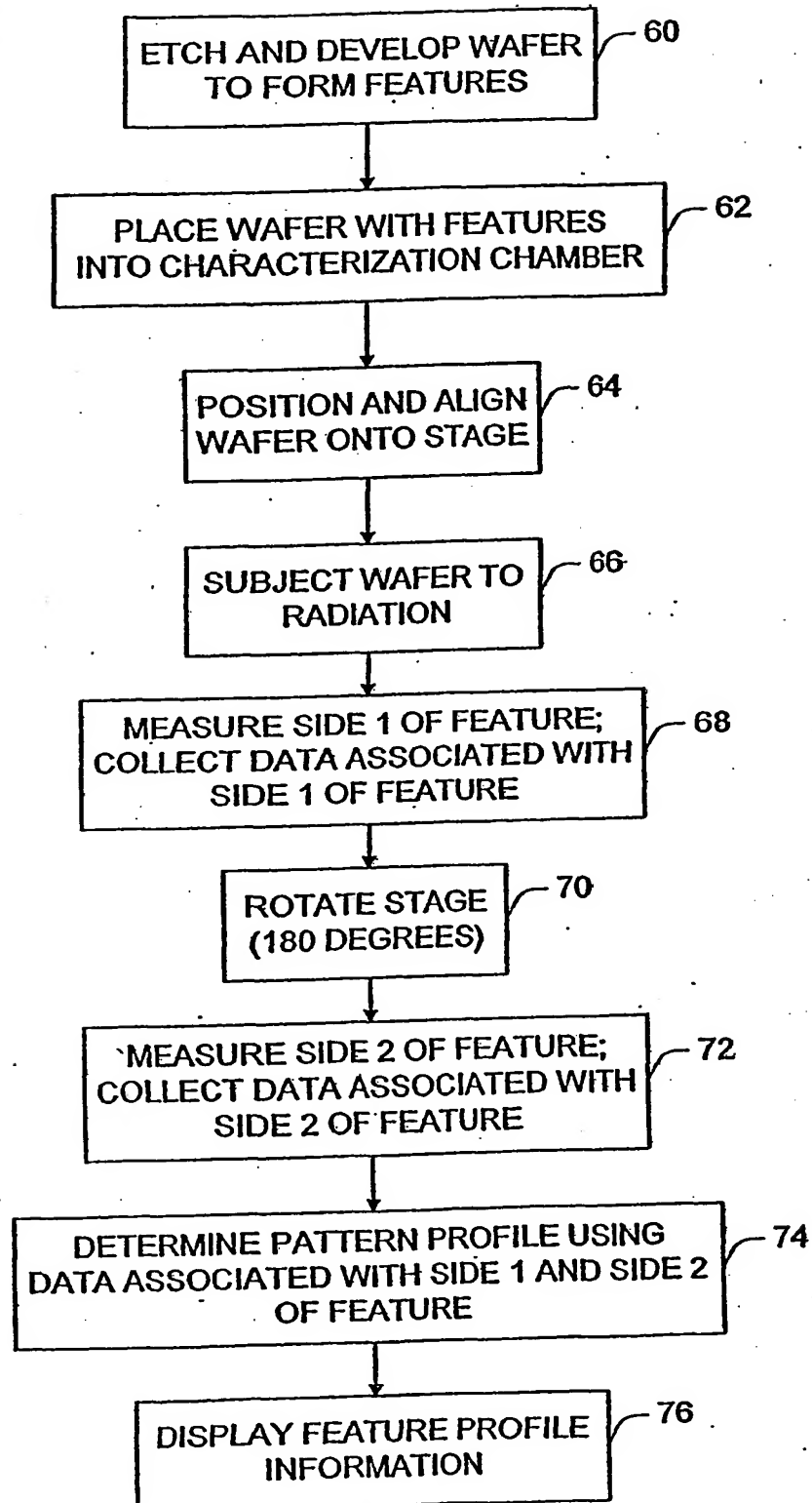


FIG. 2

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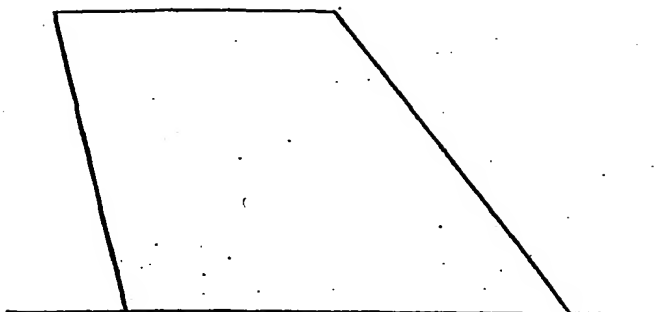


FIG. 2a

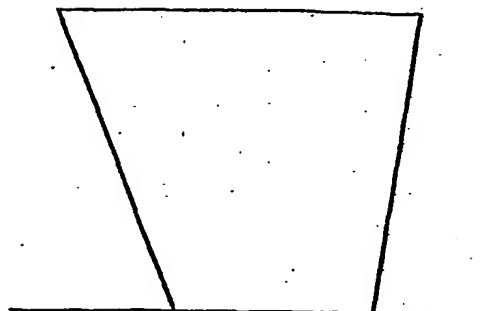


FIG. 2b

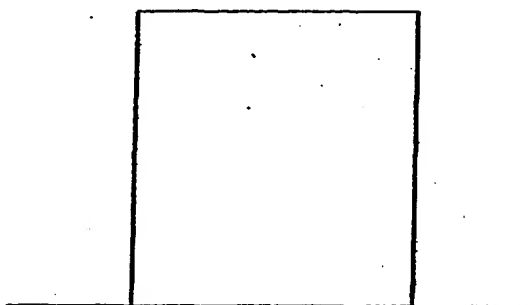


FIG. 2c

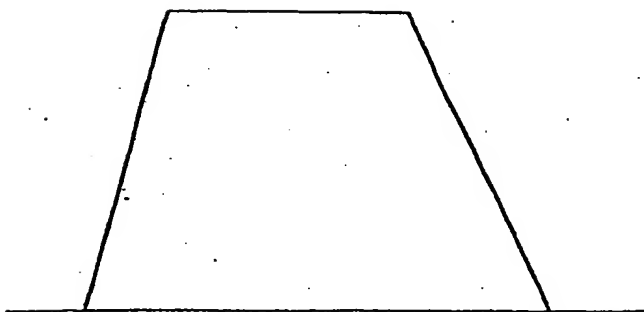


FIG. 2d

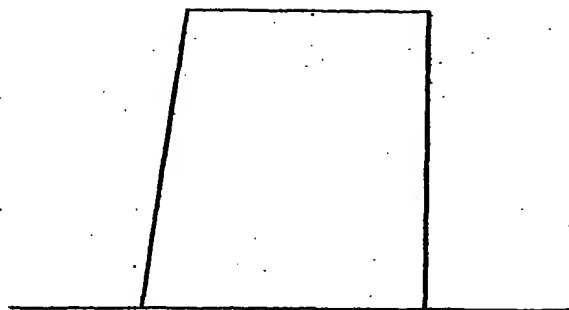


FIG. 2e

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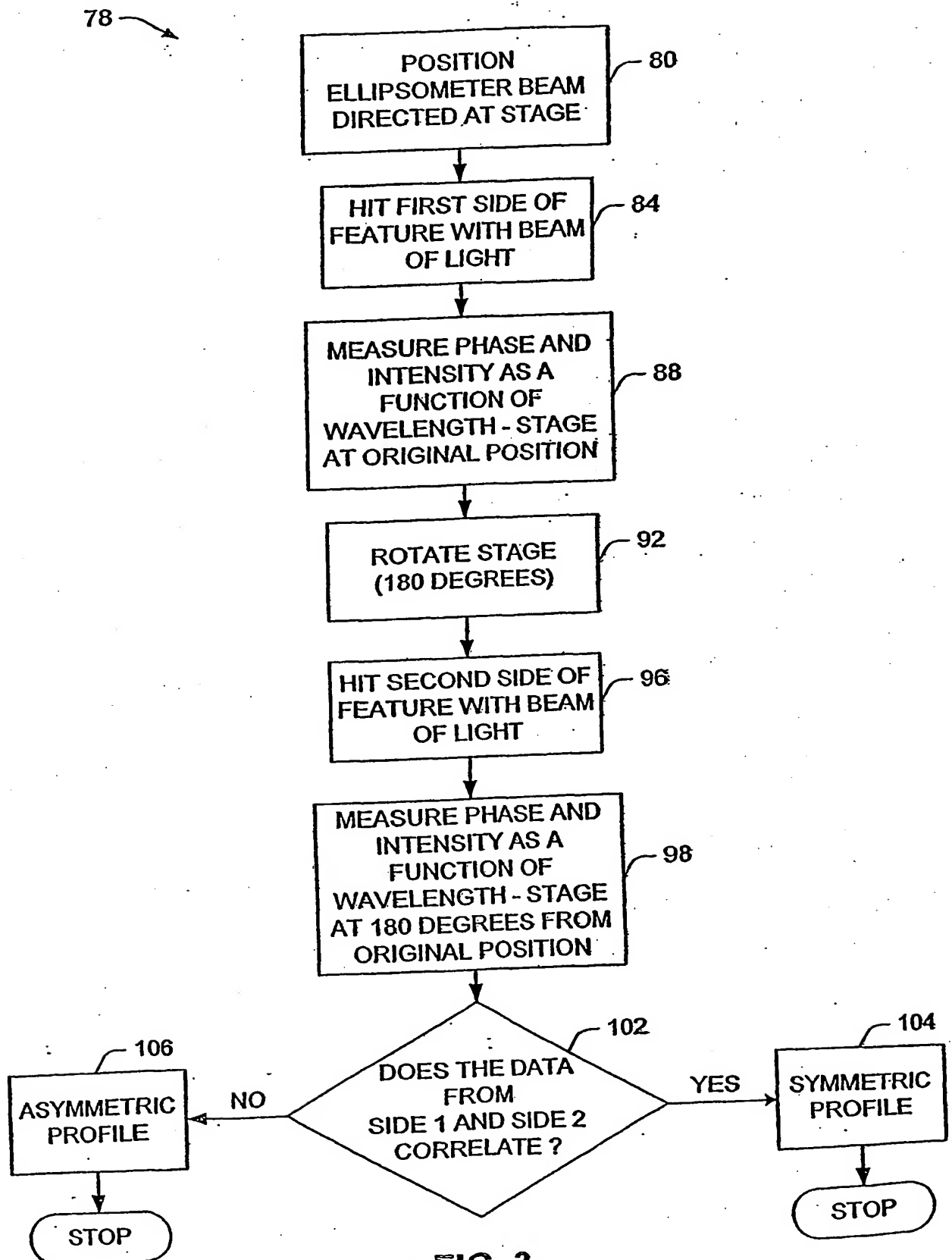
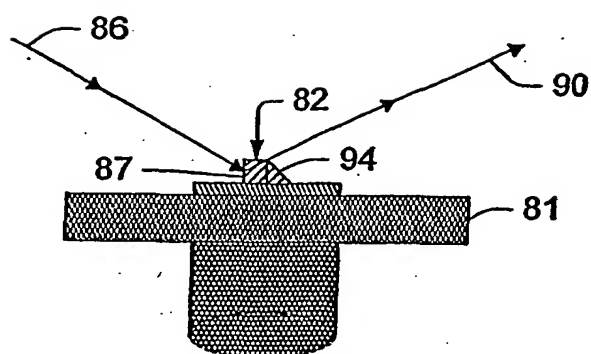


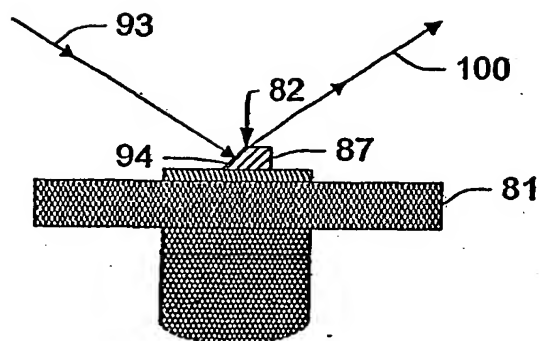
FIG. 3

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ORIGINAL
POSITION

FIG. 3a



POSITION AT ABOUT
180 DEGREES FROM
ORIGINAL POSITION

FIG. 3b

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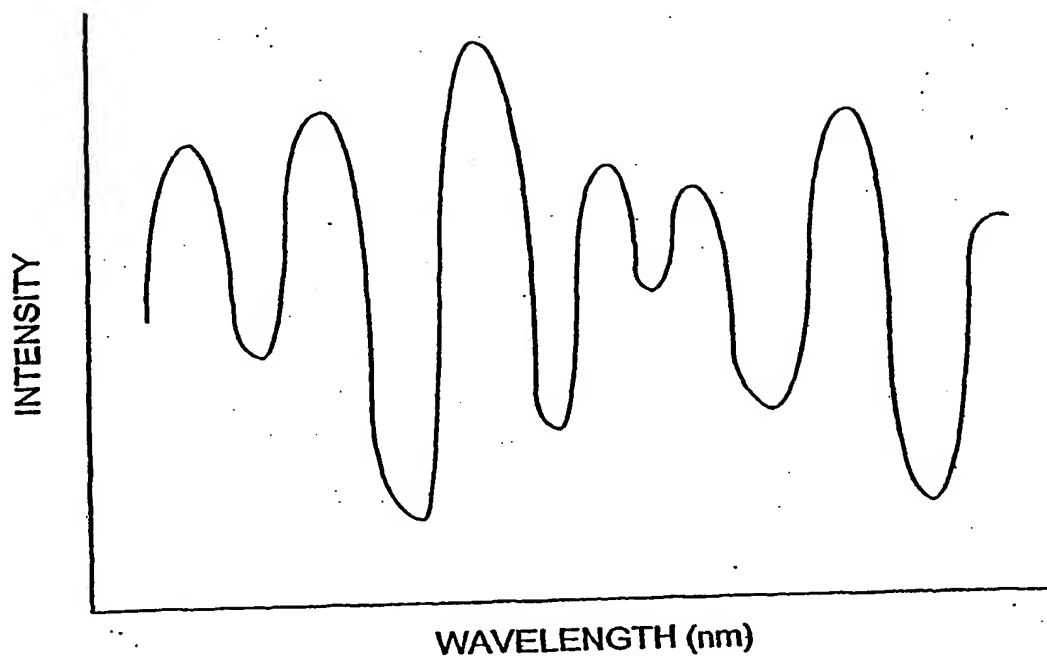


FIG. 4a

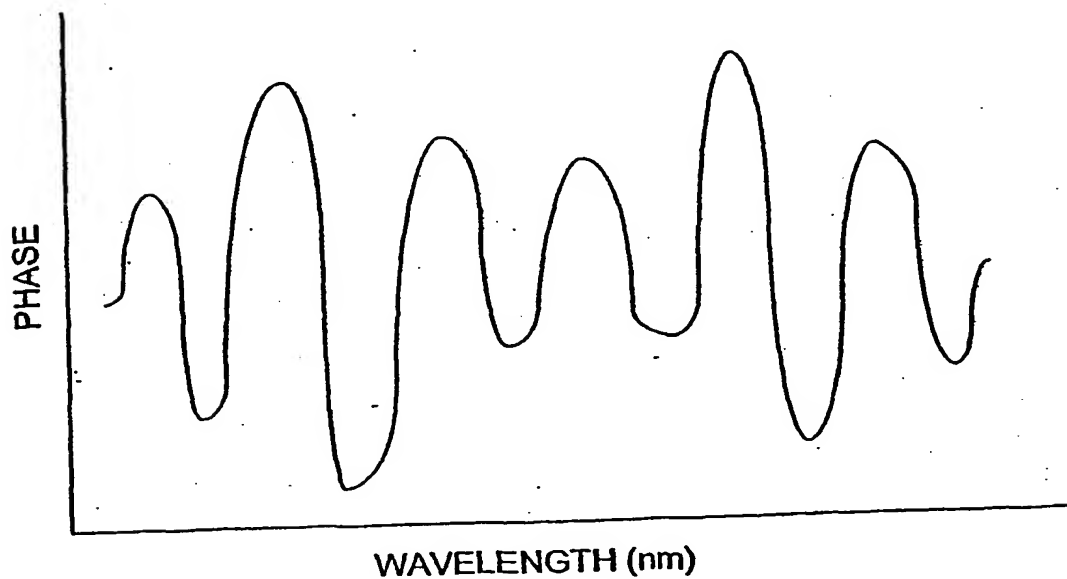


FIG. 4b

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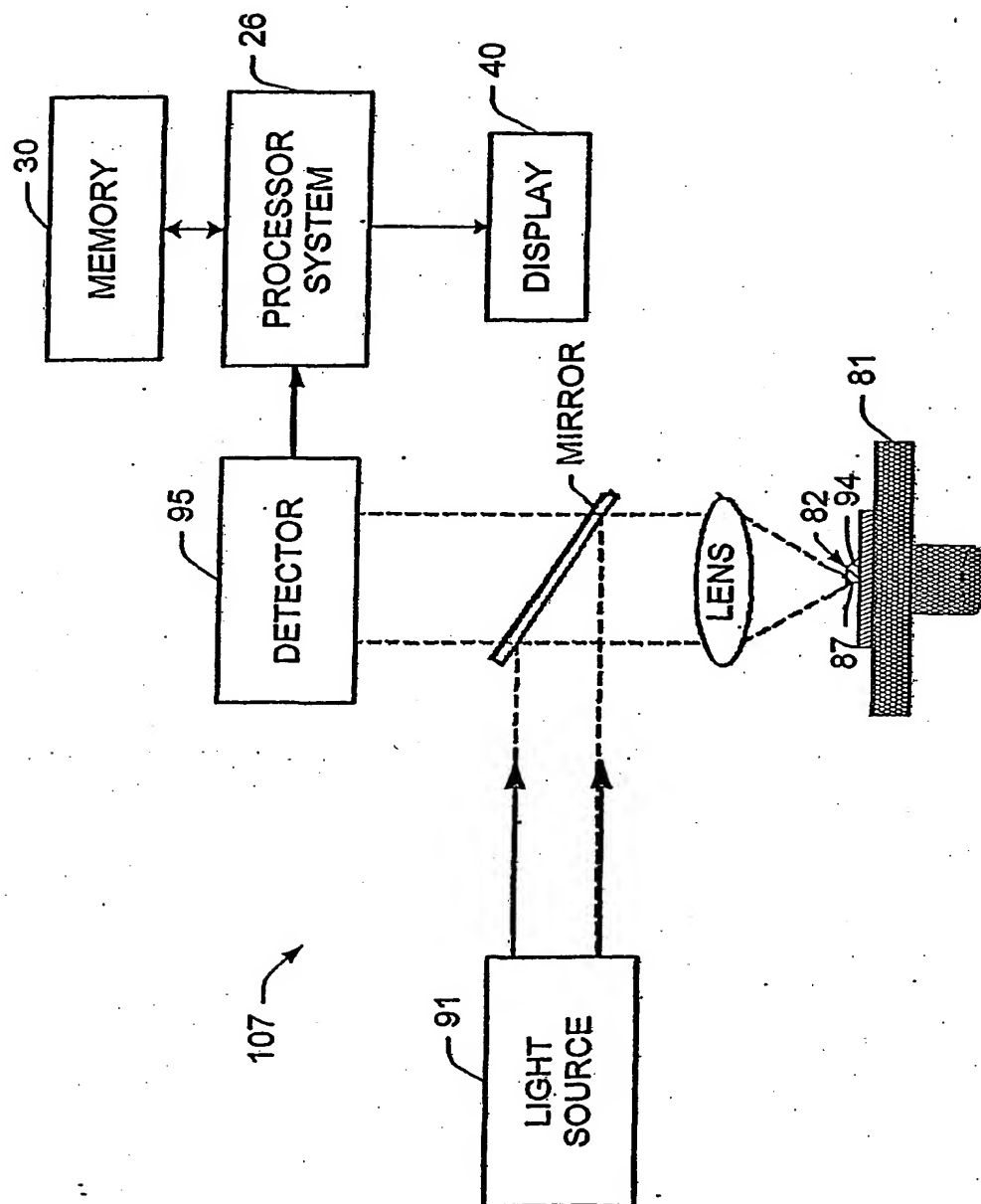


FIG. 5

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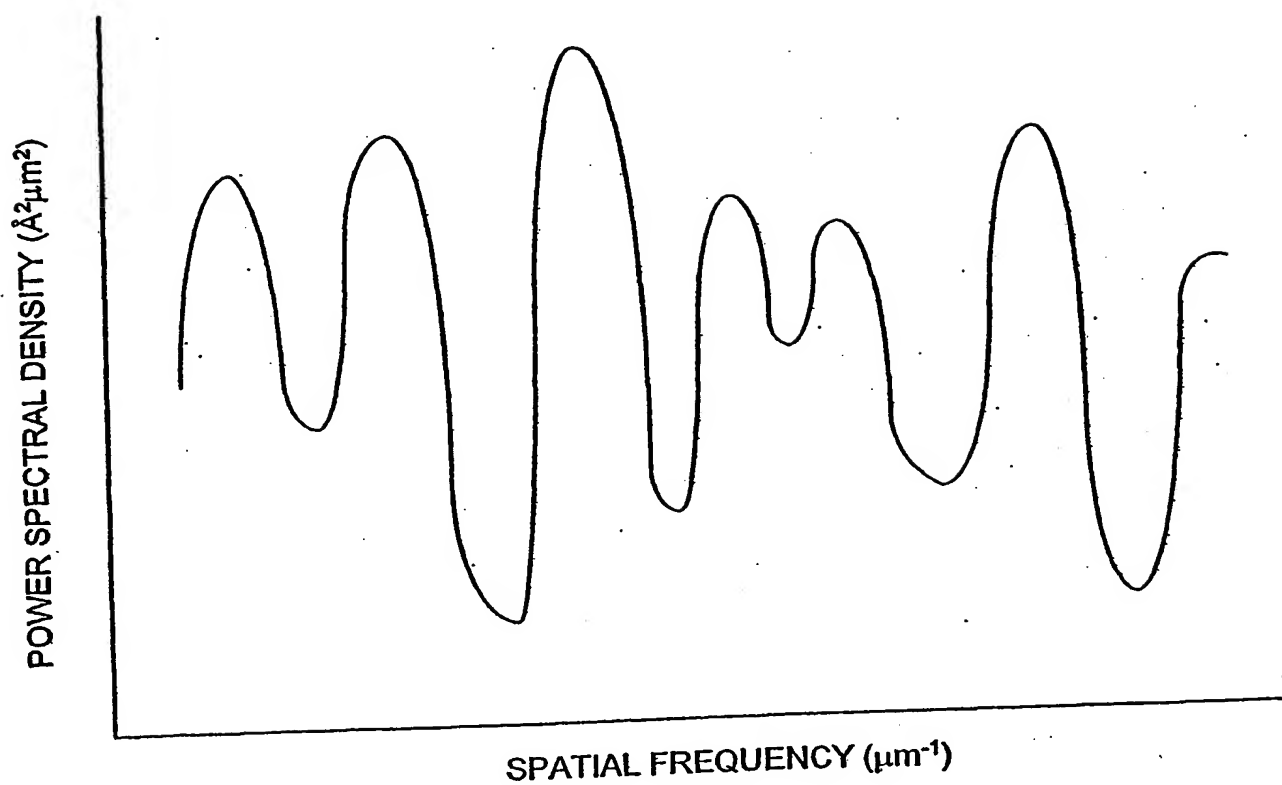


FIG. 5a

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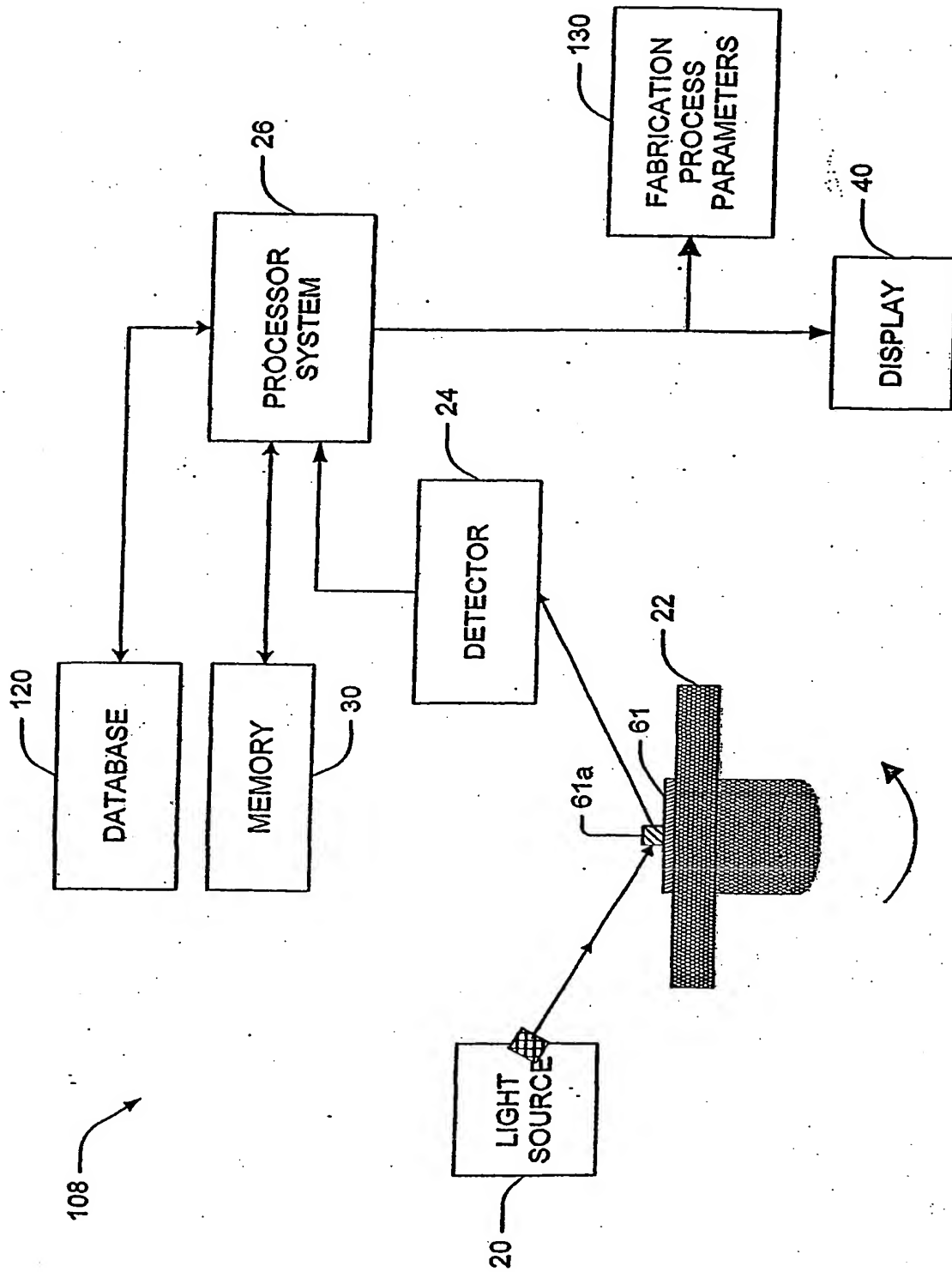


FIG. 6

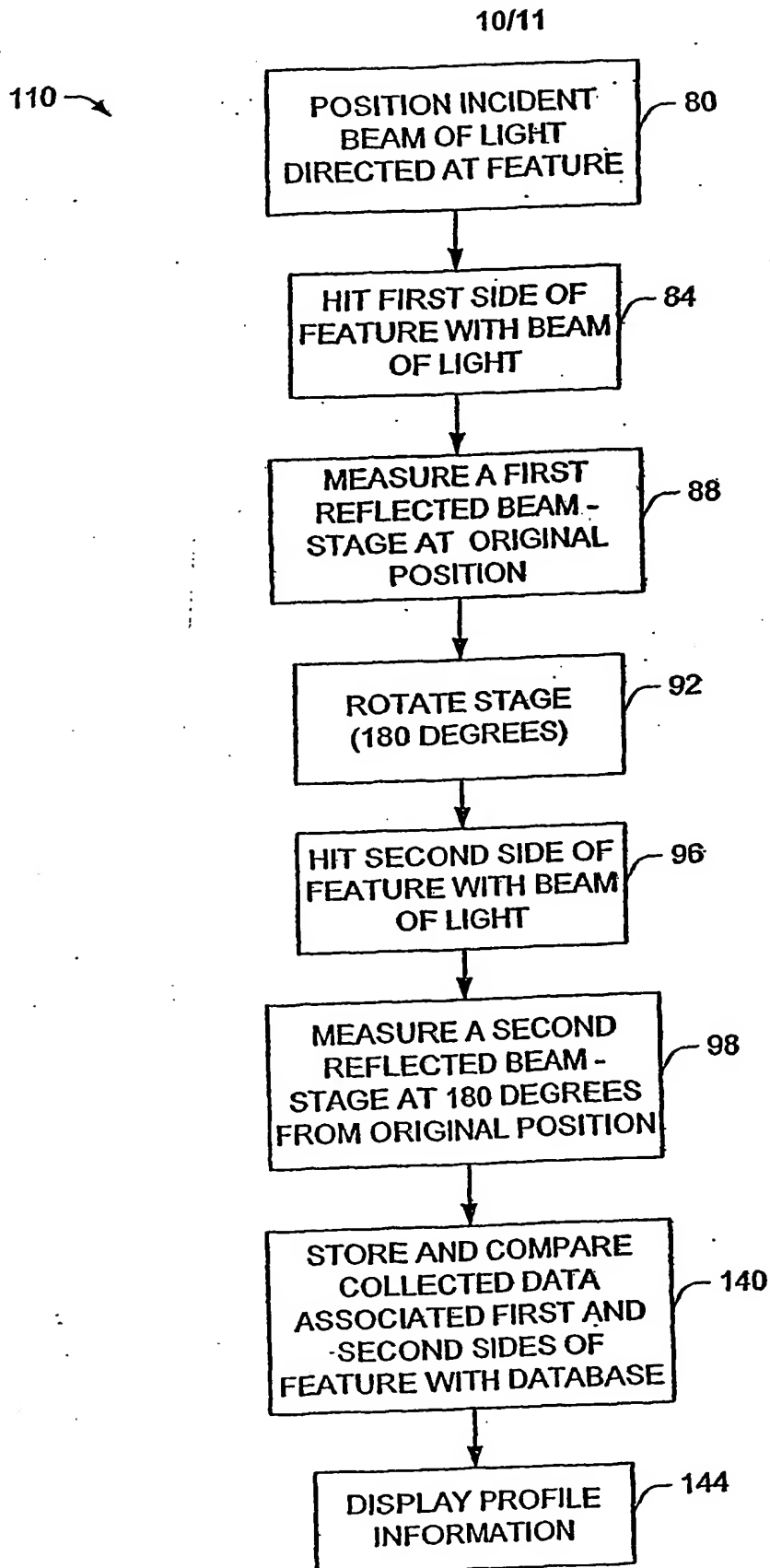


FIG. 6a

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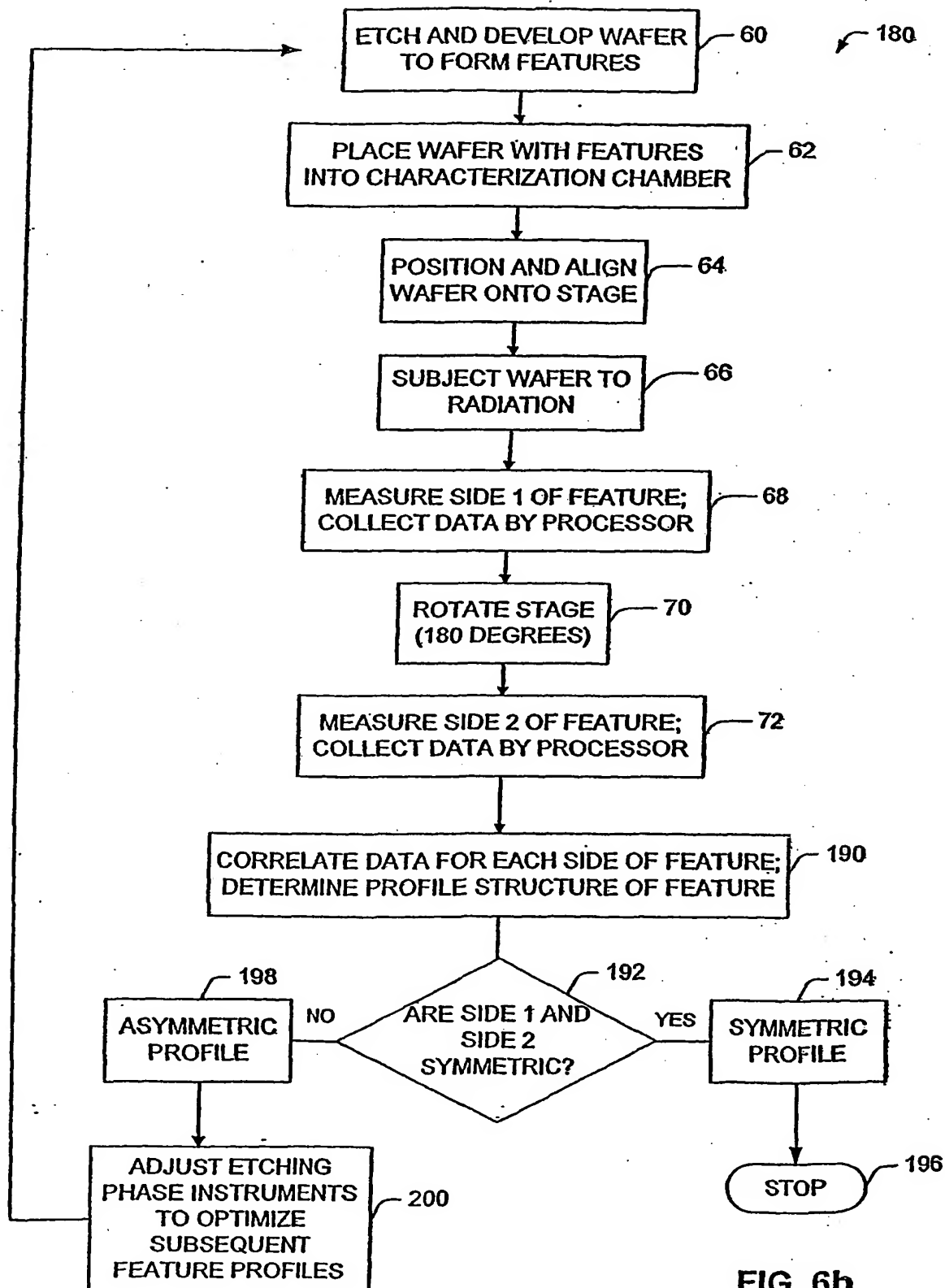


FIG. 6b

INTERNATIONAL SEARCH REPORT

Inter Application No
PCT/US 01/43805

A. CLASSIFICATION OF SUBJECT MATTER

IPC 7 G01B11/30 G01B11/24 G01B11/26 H01L21/66 G01N21/21
G01N21/47 G01N21/95

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 7 G01B H01L G01N G06T G01R

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 99 67626 A (APPLIED MATERIALS INC) 29 December 1999 (1999-12-29) the whole document	1
X	US 5 840 595 A (KOBAYASHI KATSUYOSHI) 24 November 1998 (1998-11-24) the whole document	1
X	US 6 081 325 A (WELLS KEITH B ET AL) 27 June 2000 (2000-06-27) the whole document	1
X	US 5 699 447 A (NEUMANN GAD ET AL) 16 December 1997 (1997-12-16) the whole document	6
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☒ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

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X document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

Y document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

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Date of the actual completion of the international search

3 July 2002

Date of mailing of the international search report

17/07/2002

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Arca, G

INTERNATIONAL SEARCH REPORT

Application No

PCT/US 01/43805

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	ALUMOT D ET AL: "Dual sensor technology for high-speed detection of 0.1 micron defects" PROCEEDINGS OF THE SPIE, SPIE, BELLINGHAM, VA, US, vol. 1926, 1993, pages 570-581, XP002119842 the whole document	1,6
A	US 5 544 256 A (BRECHER VIRGINIA H ET AL) 6 August 1996 (1996-08-06) abstract	1,6

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No

PCT/US 01/43805

Patent document cited in search report		Publication date	Patent family member(s)	Publication date
WO 9967626	A	29-12-1999	US 6256093 B1 EP 1090284 A1 WO 9967626 A1	03-07-2001 11-04-2001 29-12-1999
US 5840595	A	24-11-1998	JP 7253311 A US 5692070 A	03-10-1995 25-11-1997
US 6081325	A	27-06-2000	AU 3376597 A EP 0979398 A1 JP 2002513461 T WO 9746865 A1	05-01-1998 16-02-2000 08-05-2002 11-12-1997
US 5699447	A	16-12-1997	IL 96362 A US 6178257 B1 US 2002039436 A1 US 5982921 A	06-12-1998 23-01-2001 04-04-2002 09-11-1999
US 5544256	A	06-08-1996	NONE	